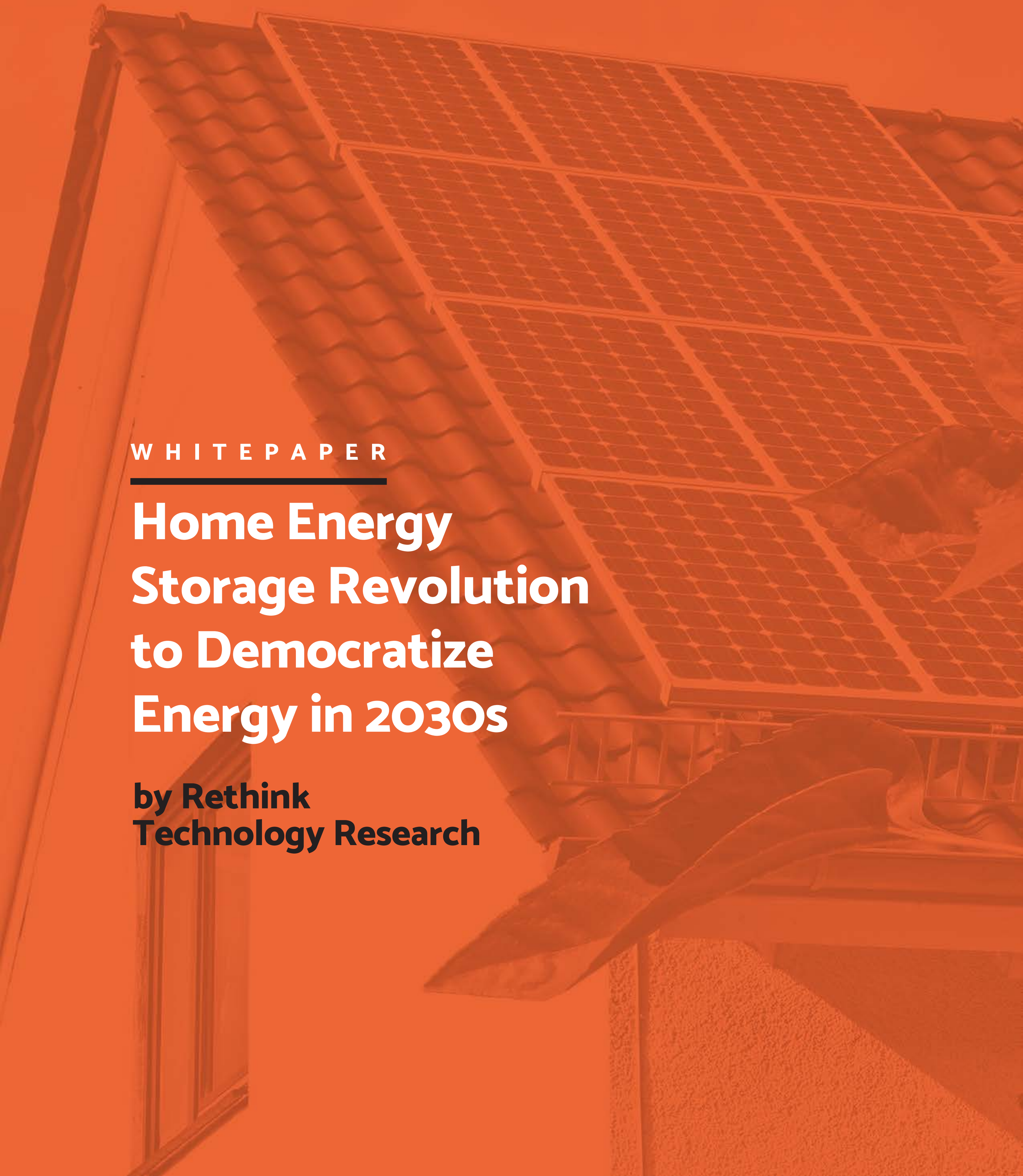

ENERVENUE

WHITEPAPER

Home Energy Storage Revolution to Democratize Energy in 2030s

by Rethink Technology Research

THE SHAKEDOWN of the world's energy sector will not be exclusive to fossil fuel infrastructure. Utility revenues, expected by many to be the beneficiaries of widespread electrification, will crumble if they cannot get a grip of the swathes of customers who could potentially benefit from going solo for their power production.

It is a stark fact that in almost all markets, rooftop solar provides cheaper electricity to consumers than utilities do.

But with weak support from feed-in tariffs or net metering, the ability to harness the true value of the technology has been stunted. That is, until the imminent dawn of low-cost, long-duration energy storage, which will bring about a new era of democratized and decentralized power generation.

As the cost of short-term, and later long duration, energy storage plummets by 2023, homes across the world will be able to afford to defect from the grid by producing and storing their own power. Some may never need to spend another cent on electricity again, generating their own energy to power an electric vehicle (EV), air conditioning or electricity for heating.

In sunny corners of the globe like Australia, Spain, California, and Arizona–which are served by expensive energy infrastructure–the cost of such systems will be so low that acceptable payback periods will be realized by customers as early as next year. Even more attractive payback periods will be recognized as

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alternative energy storage races towards economies of scale.

Markets in France, Germany, New York, Japan, Colorado, and Brazil will see huge uptake beginning in the mid-2020s. While experiencing slightly less sun or having more modest energy prices, even if these homes cannot secure all of their energy needs from rooftop solar, the financial benefits from smaller systems will still be staggering, dramatically cutting back grid revenues.

In less regulated markets, like Texas and Florida, the reduced economic advantage due to existing low retail power prices, will be offset by a driving need for energy security in the home using energy storage; achieving such low power prices has come with a stark increase in the frequency and severity of blackouts.

Can Utilities Avoid Grid Defection?

AS CUSTOMERS in these markets realize the sweeping benefits of home generation plus home storage, one-by-one, they will defect from the utility model for power that has served them for 100 years. Such technologies will be adopted exponentially, as soon as they are affordable, and can promise to add value, and once they have been seen working at the homes of friends or family.

For every customer that goes to solar-plus-battery of their own accord, less money will end up in the pockets of the utilities they have defected from. Spreading the same amount of generation facilities across fewer customers will force utilities to attempt to increase rates on non-solar customers, which in turn will convince more customers to switch to generate their own electricity.

For every customer that goes to solar-plus-battery of their own accord, less money will end up in the pockets of the utilities they have defected from.

But utilities have a way to prevent this, they can attach the CAPEX cost of solar plus storage to their rate-base and offer to fund MORE homes to go that route, but under the utility's continued control. Utilities must facilitate low-cost financing options for customers looking to purchase long-term assets that can both generate and store their own energy.

Failing to embrace the democratization of energy poses a self-promoting spiral of lost customers and lost revenue. If utilities cannot come up with a business model to offer customers low-cost ways of installing solar and home energy storage, someone else will.

This report from Rethink Energy breaks down this narrative, providing a model of where and when residential power production will reach its tipping point. It proves, with a high level of certainty, that storage technologies–such as those provided by our partner in this report, EnerVenue–will be a vital part of the transition; not just towards clean energy, but towards a future where customers control their own energy needs.

Home storage to dismantle utilities as early as next year

THE GLOBAL POWER sector is about to pay the price for its laggard approach to clean energy. In the middle of a triple-threat crisis of energy security, soaring prices and climate change, consumers will soon be in a position to generate their own power, eliminating their reliance on the grid.

Utilities which fail to adapt will face a rapid downward business spiral, as customers defect from the grid.

Presenting long-duration, low-maintenance, and safe energy storage with a high number of recharge cycles, the emergence of companies like EnerVenue will prompt a tipping point after which this will be economically straightforward, in just three years' time. Utilities which fail to adapt will face a rapid downward business spiral, as customers defect from the grid.

As the energy transition accelerates, there will be a fundamental revolution in the way energy comes to market. Distributed Energy Resources (DERs) with safe, reliable battery chemistries, will allow homes around the world to operate without being reliant on an electricity grid.

The first stuttering steps towards this are coming soon, inevitably as the combination of rooftop solar plus home energy storage becomes cheap enough for whole segments of modern society to dump their relationship with a power utility, or at least cut grid energy use significantly.

Rethink Energy, in a paper sponsored by alternative chemistry battery maker EnerVenue, has modeled the tipping points that begin in Australia, and rapidly extend to key US States, and some surprising countries–often driven by a combination of high solar irradiation and/or high retail electricity prices. Germany's high energy prices, for instance, make it a candidate for an imminent move away from grid-based electricity.

Market Forces, Technology Driving Change

THE KEY TRIGGERS have been Russia's invasion of Ukraine, coming straight after the global recovery from Covid-19, leading

Facilitated by rapid cost reductions in both solar power and battery storage technologies, the cost of a home providing almost all of its own power will fall by 66% by 2030 and 73% by 2040.

to soaring prices for oil and gas–up 53% and 72% respectively year-on-year. This has meant that retail power prices have risen by up to 40% in many global markets. Many customers have been plunged into a state of energy poverty, with their bills accounting for over 10% of their annual income.

The bad news for consumers is that such prices are unlikely to rapidly fall by very much. Historically utilities have rarely reduced the cost of electricity to the customer. Instead, they capitalize on high margins to bolster their bank accounts, which will be needed to offset stranded fossil fuel assets that are set to become uneconomic in the next five years, as they are undercut by renewables-plus-storage installations.

Meanwhile, the access to solar-plus-storage technologies, in particular, are becoming democratized. Facilitated by rapid cost reductions in both solar power and battery storage technologies, the cost of a home providing almost all of its own power will fall by 66% by 2030 and 73% by 2040. In just three years, according to research conducted by Rethink Research on behalf of EnerVenue, the continuing falls in the cost of home solar plus storage will drive down the cost of going off grid–literally.

Having fallen in price by over 82% through the past decade, continued economies of scale will see the raw costs of solar power fall by 67% by 2040, while markets like the US, which are currently plagued by soft costs, will see a competitive landscape drive the global total cost of solar to between $600 and $720 per kW.

Solar + Storage

GUARANTEEING ENOUGH power to supply one home for one whole day will require the average home to install nearly 18 kW of solar power. With nearly half of household demand coming at times that are typically outside of daylight hours, battery storage will be needed for full grid independence. Overcapacity will also be needed to account for times when solar output is lower than average, or when household demand is higher than expected.

Residential solar-plus-storage systems will also need to be future proof, designed for the wave of electrification that is set to come across the vehicle

Crawl spaces, attics, high ceiling areas and even the siding of commercial structures all offer potential for storage capacity.

charging, heating and cooling at the household level. With electric technologies penetrating each of these technology areas, and only offset partially by efficiency improvements across the home, the average home will be using 33% more power in 2040 than it does today. This figure will be as high as 65% in markets like California, which are rapidly accelerating policies to decarbonize homes.

Because of this rise in demand, solar-plus-storage systems will have to scale accordingly. Even in emerging economies like Brazil, the average home will need 11 kW of solar capacity, paired with 9.9 kWh of battery storage. Power hungry economies like Texas will require 23 kW of solar with 48 kWh of battery, while countries with weaker solar resources, like Germany, will require 22 kW of solar with a 9.7 kWh battery.

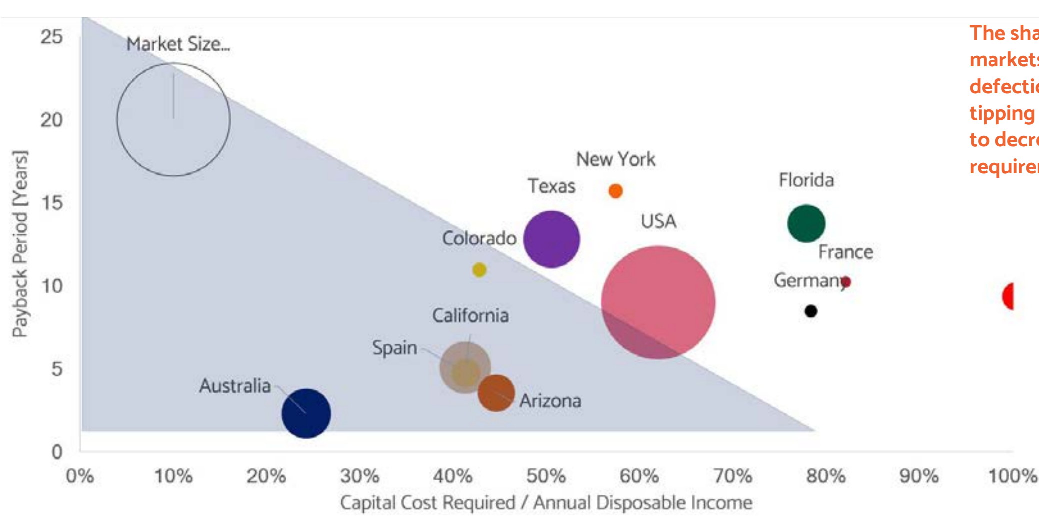
Adoption Considerations

AND THIS IS FOR the average home. Larger homes, normally owned by higher earners, are likely to be faster to adopt solar-plus-storage systems due to their available capital. These larger homes will also be likely to have sufficient roof space for the required solar power (1 square meter per kW) and will also require larger systems for their greater levels of consumption.

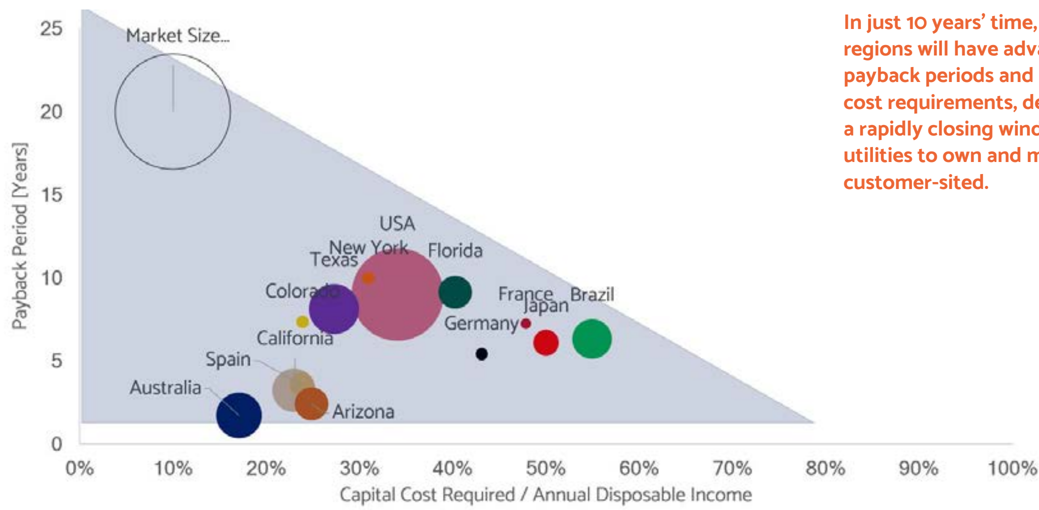
For these users, the demands for home battery storage will vary from those normally associated with electric vehicles. To maximize capacity, battery storage should be crammed into any available free space in a home. Crawl spaces, attics, high ceiling areas and even the siding of commercial structures all offer potential for storage capacity. But to do this successfully, systems will need to be extremely safe and need almost no maintenance over a lifetime of at least 20 years to match that of solar.

This is where lithium-ion falls short. The average lithium-ion battery costs around $20 per kWh per year to operate and maintain; often over its lifetime OPEX costs can exceed the initial capital requirement. The explosive nature of the failure of lithium-ion also poses significant risk for both homeowners and insurers.

Alternative chemistries, such as the metal-hydrogen battery developed by EnerVenue, offer a solution to this, while also skirting around the supply issues that will plague an EV-dominated lithium-ion industry. With no moving parts, no risk of fire or thermal runaway, no O&M requirements,



The shaded area represents markets where grid defection has reached a tipping point by 2025 due to decreasing capital cost requirements.



In just 10 years' time, almost all regions will have advantagoues payback periods and affordable cost requirements, demonstrating a rapidly closing window for utilities to own and manage customer-sited.

and demonstrated durability in operation, these technologies will provide the backbone for the home-storage revolution of the late 2020s.

And these technologies are far earlier on their cost-curve than lithium-ion, which has fallen in price per kilogram by over 88%, to $138 per kWh in the past decade. Upon the opening of its manufacturing facilities in 2023, EnerVenue expects the production costs of its battery to fall significantly. Having secured a pipeline of sales across its utility-scale and C&I segments, economies of scale and a reduced reliance on third-party suppliers, could see costs fall to below $100 per kWh by 2030. By 2040, EnerVenue's battery capital costs will be cost-competitive with Lithium Ion, while providing significant benefits in safety and maintenance.

> **Rethink Energy believes that the mass-uptake of solar-plus-storage will start when the average payback in that market is around 7.5 years.**

The cost reductions in solar and storage technologies will see the cost of the average system for home self-sufficiency fall from $66,000 in the addressed markets, to less than $18,000 by 2040.

Trailblazing Markets

IN MARKETS like Australia, with exceptional solar potential and low installation costs, sufficient solar and EnerVenue storage capacity can already be installed for just $25,000. Given the country's high retail power price, the amount that customers will save from not buying grid-based power and what they will earn from selling excess solar power back to the grid, already creates a payback period of 5 years, which is well within the desirable range for consumers.

Based on the rapid uptake of rooftop solar in specific markets, as well as other home-improvement technologies, Rethink Energy believes that the mass-uptake of solar-plus-storage will start when the average payback in that market is around 7.5 years, with a capital cost accounting for less than 45% of a home's disposable income.

In Australia, this tipping point is about to happen with the inauguration of EnerVenue's new production facilities, facilitating a payback period of four years that will trend down towards two years by 2040. Led by high-income households, uptake can then be expected to accelerate in markets with strong solar resources and prices–such as Spain and the US State of Arizona–as well as markets with

In many markets, the three conditions for mass adoption are now being met: "I want one, I can afford one, and I know someone who has one."

high retail power prices–such as California, Japan, and Germany–between 2023 and 2026.

Markets with low retail power prices (Florida, Texas), weak solar markets (France, New York), or low income (Brazil), will experience acceleration slightly later–between 2029 and 2037.

Once these criteria are met, the three boxes will be ticked for consumers looking to reduce their reliance on the grid using home energy storage: In many markets, the three conditions for mass adoption are now being met: "I want one, I can afford one, and I know someone who has one." Suddenly, a huge number of customers will defect from the traditional utility model.

Without these customers, who are providing their own electricity, slow-to-adopt utilities will be trapped with too many generation facilities producing too much electricity for too few customers. They will look to governments for bailouts to retire their expensive fossil-fuel infrastructure ahead of schedule, and in most instances will be unsuccessful. Instead, the bill for shutting down old coal and gas plants will be pushed onto the consumer, and retail power prices will rise even further. Higher power prices will see more customers defecting to solar-plus-storage, until these companies can no longer sustain operations. As a customer led revolution, the speed of this spiral will be staggering.

Survive or Thrive?

THE ONLY WAY for utilities to survive, especially in the markets that have been outlined for early adoption, is to embrace the decentralization of power production. They must themselves start offering low-cost subscription packages to customers that are looking to install rooftop solar and storage, offsetting the initial capital cost. In effect, they will accelerate this market trend, but keep control of it and retain a viable business, eventually with better margins. Utilities which first embrace this trend will acquire significantly greater market share than slower rivals. It will also provide a way of penetrating neighboring utility markets.

Under utility control, aggregating these installations at a neighborhood level will help to create virtual power plants (VPPs) to replace coal and gas plants which they are forced to retire, while any investment in new facilities is halted immediately. This will be costly at first, but the ability to attract customers from competing utilities that have failed to adapt will be easy, and will be bring huge subsequent growth.

Several steps need to come from policymakers to incubate this growth. Incentives must be implemented for the adoption of rooftop solar and storage in new construction and for retrofits into existing structures. This

should aim to offset the cost for early adopters of the technology. Feed-in tariffs and metering schemes must also allow operators of home storage systems to compete with utility-scale providers in all markets, allowing for maximum revenue to be made from excess clean power generation and for overcapacity to be incentivized.

EnerVenue: Long-duration, Home Energy Storage

FOUNDED IN 2020, EnerVenue remains in an early phase of its rapid development. Having sold only 2 MWh of battery capacity as of the end of 2021, the company's pipeline outlines a seven-figure percentage growth in just six years. It has already made sales amounting to over 5 GWh over this period.

As the company's technology matures, benefiting from new production lines next year, the economies of scale that this will bring has the potential to drive down production costs significantly.

That technology is an improvement upon an established NASA design used in several high-profile applications like the Hubble Space Telescope and International Space Station.

As the battery charges, hydrogen is chemically created, then releases energy as it is reabsorbed into water. This hydrogen evolution/oxidation reaction is well known and not subject to the degradation effects that impact lithium-ion. It is exceptionally stable and durable. The cells operate for 30 years, 30,000 cycles of three cycles/day. It can be charged fast or slow.

The battery is significantly less energy dense than lithium ion and won't be a candidate for electric vehicles. But this is where its disadvantages end. The system won't suffer from thermal runaway, offsetting the risk–and growing insurance cost–of installing it in a home battery system. The reduced energy density can be mitigated by filling wasted space in a home with valuable battery capacity without homeowners worrying that the system will need to be maintained or that it will spontaneously combust.

It also won't decay after a few thousand charge-discharge cycles. With an available 20-year/20,000 cycle warranty, and a lifetime far beyond that, the system will be well paired with rooftop solar. Maintenance requirements and operational costs will be negligible, compared with that of lithium ion, where lifetime OPEX costs can often be as high as the initial CAPEX requirement.

The ability to run additional cycles will also allow greater flexibility in operation. While residential demands will typically

Maintenance requirements and operational costs will be negligible, compared with that of lithium ion, where lifetime OPEX costs can often be as high as the initial CAPEX requirement.

be satisfied by one charge-discharge cycle of a battery powered by rooftop solar each day, the ability to run additional cycles–without worrying about the battery's lifetime–opens up huge potential for arbitrage. Users will be able to purchase low-cost energy from the grid when supply is high, and sell it back for profit at times when prices are high.

From a material perspective, lithium ion depends on the supply of both lithium and other rare earth metals–cobalt and manganese for instance, both of which are facing soaring demand in the EV space. EnerVenue relies on two of the most plentiful things on the planet: Nickel and the compound water. The EnerVenue catalyst is billed as 1,000 times cheaper than platinum (which the NASA batteries used), and does not use any rare metals at all. You could build it anywhere with local supplies, with the system weatherized to operate anywhere from minus 40 to positive 60 degrees Celsius

A Manifesto for Utilities

THE CLOCK IS TICKING for utilities that don't want to get left behind in this fourth revolution of the power sector. Many have been resting on their laurels, waiting for customers to come to them as power demand rises, as sectors from transport to heating get electrified. But to ensure that customers do not defect from the grid and produce their own electricity using solar-plus-storage technologies, utilities will have to change their business model.

The clock is ticking for utilities that don't want to get left behind in this fourth revolution of the power sector.

1. Allow home energy systems to compete with utility-scale assets on real-time energy markets
2. Offer flexible-leasing arrangements for the installation, maintenance, and use of rooftop solar and battery capacity–maximizing the adoption of capacity at each property
3. Aggregate residential assets, owned by the utility, into VPPs to ensure energy security at residential, neighborhood, and grid-level, from the bottom up

The first step here is to embrace the boom of rooftop solar. Taking inspiration from markets that have already witnessed exceptional growth, like Australia and California, utilities should initially embrace net metering or feed-in-tariffs to incentivize adoption, while removing any grid connection fees for the consumer. Users must be able to profit from making green decisions.

One key theme will be the promise of electricity going down in price immediately, in contrast to the gas driven electricity market, which has had such a huge spike in prices globally due to the Russian Ukraine war.

Unique Markets Require Unique Pricing Schemes

HOWEVER, these schemes need to evolve with the markets they are present in. Providing a fixed rate for rooftop solar input may not be practical in grids that are becoming increasingly reliant on utility scale, which can be bought at variable rates. The ability to sell electricity back to the grid at generous rates may,

The first step here is to embrace the boom of rooftop solar.

The cost of new storage technologies poses a significant barrier to entry for many customers and can only be offset by either subsidizing the initial capital cost or decreasing the pay-back time by increasing the revenues generated by the system.

in fact, slow the adoption of self-sufficient systems at first.

The cost of new storage technologies poses a significant barrier to entry for many customers and can only be offset by either subsidizing the initial capital cost or decreasing the pay-back time by increasing the revenues generated by the system.

Reducing the rates that customers can receive from exporting rooftop solar—as seen in the NEM3.0 proposals in California—will incentivize the adoption of home energy storage but may conversely reduce the adoption of rooftop solar itself.

To incentivize both, home energy systems should be allowed to compete in short-term energy markets, where price fluctuations—and potential margins—are significantly greater. If a system can buy electricity at €20 per MWh on the German Intraday market at 5.45am when power supply is high and demand is low and can then sell it at 8.30am when demand ramps up, it may be able to sell it for over €60 per MWh making a 200% gross profit. As the penetration of renewables increases, the extent of this price fluctuation, and thus the business case for smart storage systems, increases in tandem.

Such market structures provide the optimum conditions for the adoption of both rooftop solar and home energy storage, but do not explicitly offer the utility an advantage. To capitalize on such technologies, the utility needs to make sure that they are the owners of the generation and storage assets.

Utilities as Asset Owners

THEY SHOULD CAPITALIZE on their available funds to offer simple subscription models for users looking to produce their own energy. Leasing models could be scaled-up or down to include rooftop solar, home energy storage, electric vehicles, V2G charging and other clean energy assets, which can have some level of interaction with grid-level dynamics.

The scale of utilities should be used to create a standardized and straight-forward installation and maintenance process, included within the cost of the subscription, that has minimum disruption to the homeowner.

With utilities typically operating on net profit margins of around 10%, utilities should be able to offer users a self-sufficiency package, comprising of rooftop solar and a battery, at an average monthly fee of around $117—a 7% saving compared to the average monthly electricity bill. By 2040, such leases will offer customers savings of more than one-third.

The utilities advantage here lies in its ability to aggregate systems together to produce virtual power plants (VPPs). On a hyperlocal and decentralized level, energy security can be achieved from the bottom up—rather than the top-down approach that has dominated for over a century. Supply should be focused on satisfying household

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demand, before expanding out to neighborhood demand, and then the full grid level demand.

Localized generation will be far more efficient and will not be subject to the same level of transmission losses as present when using large, centralized power station resources. By aggregating all of these residential assets, utilities will have

In this sense, the utilities' greatest asset–both on the supply and demand side–will become the consumer.

a diversified portfolio of assets and will also be able to provide ancillary services to the grid.

In this sense, the utilities' greatest asset–both on the supply and demand side–will become the consumer: the space on their rooftops; their capacity to house battery storage; and the electricity they use.

METHODOLOGY

DETERMINING THE cost advantage of solar-plus-storage over retail electricity requires a deep understanding of each market. Future technical advances and technology costs need to be projected, along with the penetration of different generation technologies within each standalone market.

And while these factors are dependent on a range of geographic and economic data, individual solar-plus-storage systems are constrained by maximum installation sizes. Their ability to provide undisrupted power is naturally dependent on how much power is required–and at what time of day that it is needed. To some extent–with unpredictable variations in load and solar output–it is impossible to say that a home can ever be 100% independent of the grid, without some risk of power shortage.

Within the model created for this study, the 'number of days that the grid is required' is a function of solar variation and fluctuations in household power demand. To say that the grid would be required for just one in every ten days is to say that there is just a 10% chance that the solar output from a given day will be insufficient to satisfy household demand, when paired with sufficient storage.

SOLAR OUTPUT

PROFILING SOLAR output is fairly straightforward. Using solar irradiation data, a distribution can be fit that identifies the probability of a panel outputting a given percentage of its rated capacity at a given time of day. Naturally, in markets that experience more overcast weather, or experience seasonal variation to a greater extent, this curve is flatter.

Profiling household electricity demand is trickier, and often depends on device-level data. It is important to know how many people within each market have electric heating systems, air conditioning and electric vehicles, and how this will change through a broad economic shift towards electrification, but also over time these devices–as well as those in plug-based appliances, lighting, and cooking–become incrementally more efficient. Based on behavioral characteristics in each of these markets, the variation in daily usage can also vary. In markets like the US, for example, the average distance driven per day is double that of markets like France, but also varies massively between households.

Once the variation of usage across all devices is accounted for, the relationship between a house's rooftop size, and its expected daily power demand, must also be considered. Larger houses, as expected, use more electricity, but this relationship is not linear. While more space may require more lighting and heating, there is less of a correlation between household footprint and electricity demand for cooking.

ELECTRICAL USAGE AND RATE SCHEMES

THIS VARIATION in daily demand also plays into the average monthly and annual amount of electricity a home purchases over a month or year. Most markets operate on a tier-based system, where users pay a fixed fee, rate A for electricity used up to a certain volume, and rate B for electricity used over that volume. Some are split into even more tiers. Assessing the rates offered in each market, and the expected household demand, provides an estimated cost of retail electricity.

Retail power prices seldom go down. Even in the energy crisis we are in today, the long-term outlook for prices–to the consumer at least–is upwards. Utilities will soon be faced with the additional costs of retiring redundant and stranded assets ahead of time and will be forced to push that cost onto the consumer. As such, Rethink Energy predicts that the average power prices seen in 2021, will rise by 12% over the coming decade.

Meanwhile, the cost of producing your own electricity at home will decrease.

FALLING COSTS

THE COST of solar modules has already fallen by 82% over the past 10 years. Hard costs of solar typically follow a learning rate of around 23%, meaning that the cost of module production falls by 23% every time the globally installed capacity doubles. Rethink Energy has forecast that global solar capacity will grow from 909 GW in 2021 to over 13,509 GW by 2040, which will see the cost of solar modules fall by 43%.

This is only half of the picture in the residential space. Currently, soft costs associated with sales, permitting, inspection, margins, and interconnection account for nearly 65% of installation costs in some markets. Others, where rooftop solar has already enjoyed an early boom, such as Australia, has seen competition largely eliminate this. As more expensive markets catch up, these soft costs will fall much more rapidly, and global prices will converge.

Similar mechanics can be applied across the operation and maintenance of rooftop solar, while technical advances also extend the lifetime of solar panels and increase their capacity factor and output. The degradation of the solar output over its lifetime, however, must also be considered.

Combining the varied output of a given megawatt of rooftop solar capacity with the fluctuation of household demand means that we can define the overall solar capacity–and cost–of a rooftop solar installation. Looking at the mismatch between the two, combining their variation, can be used to determine the required amount of energy storage.

ENERGY STORAGE CYCLING

WITH ONE CYCLE per day, it can be roughly assumed that excess solar power can be used to charge the battery during the day, before it is discharged during the evenings, as well as overnight for things like EV charging. The volume of battery capacity that is required can therefore be approximated as the absolute sum of the energy that is used, above that being provided by the rooftop solar, in the hours where a net discharge is occurring.

Given that we are building for energy security here, most days will see much of the solar and battery capacity left unused. With markets offering various rates for consumers to feed electricity back into the grid, customers will be compensated for this overbuild of residential capacity.

The price of battery capacity is therefore the key factor in determining the cost-competitiveness of solar-plus-storage systems. Chemistries, particularly those that are not lithium-ion, are at a much earlier stage of their cost-reduction curve than solar power. With a similar route to commodification, and economies of scale, a similar learning rate can be expected for companies like EnerVenue. As sales grow across utility-scale and C&I segments, the price of residential batteries will fall from around $300 per kWh to below $100 per kWh, while OPEX costs and degradation rates remain negligible.

Given the savings that customers can achieve by reducing their reliance on retail power and the revenues they can make from selling excess power back to the grid, the LCOE of a solar-plus-storage system can be compared directly to that of retail power prices in each market, and as each market develops through to 2040. These savings can be compared to the overall system cost to determine an overall payback period for the customer, which provides a key indicator of when mass adoption of the technology will take place. It's sooner than you might think.

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APPENDIX

Summaries by Region

- Australia
- Brazil
- France
- Germany
- Japan
- Spain
- USA
- California
- Florida
- Colorado
- New York
- Arizona
- Texas

Australia

AUSTRALIAN HOMES could be among the first to eliminate their requirement for grid-provided electricity. As many as 46% have sufficient roof space to survive without a grid connection today if they are willing to spend close to $24,188 on a rooftop solar plus battery system. Apart from maintenance they may never need to spend another cent on electricity again, including the electricity to power an electric vehicle.

Based on the outlined costs of rooftop solar and of EnerVenue's technology, the average home may be serviced by a solar-plus-storage system costing $24,118 in 2022, falling to $9,238 in 2030, and $9,120 in 2040.

With an LCOE of $82 per MWh–a 68% reduction compared to retail electricity–today's payback period of 6 years is already below the 13-year threshold that is necessary for widespread adoption. By 2026, the payback period could fall to a plateau as low as two years.

Australia also benefits from a high level of disposable income among its population. The proposed solar-plus-storage system will only account for 18% of total disposable income by the middle of the forecast period; below the 45% figure that is believed acceptable based on historic levels of savings.

With high temperatures spanning across the country in the summer months, Australia's need for air conditioning–present in 49% of homes–accounts for 38% of residential power demand; a figure that is set to grow as the climate warms and as homes have more disposable income. Already , the average Australian home uses around 7,200 kWh of power per year–significantly higher than the global average.

This figure is set to rise to 9,500 kWh by 2040, as electric heating systems are installed in 43% of buildings, up from 16% today, and as EV adoption rises to 75%, from just over 1%.

With air conditioning primarily used between the hours of 5pm and 9pm, the intraday fluctua-

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tion in hourly power demand in an Australian home is around 1.3 kWh. It will fall only slightly to 1.1 kWh by 2040, as smart technologies are adopted to distribute load throughout the day.

To ensure sufficient solar power is produced to power an Australian home on 90% of the days each year–considering the variation in solar output and household demand–an average rooftop solar capacity of 10.4 kW is required today, rising to 12.7 kW as EV and electric heating adoption increases.

To ensure that this power can be provided through the hours when it is most required, this should be paired with an average battery capacity of 18.5 kWh, rising to 22.5 kWh by 2040.

Australia is a country with exceptional solar potential. The country's average direct solar irradiance is higher than that seen across continental Africa, with 6.82 kWh of solar energy hitting every square meter per day. In theory, there is enough solar energy falling on less than 1% of Australia's surface area to produce satisfy of the country's need for electricity.

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But having built its energy system on coal, and with a reliance to distribute energy for hundreds of kilometers between its load centers that are largely dotted around the country's coast, electricity prices for Australia's people are far from cheap. While it varies from state to state, as outlined below, the average Australian spends around $259 per MWh of electricity.

The ability to capitalize on the country's vast solar resource has led Australia's rooftop solar into global pole position. Rooftop solar has surged, powered by the combination of Feed-in Tariffs–which now vary between 8.5 and 10.2 cents per kWh, depending on the state–as well as territorial subsidies on the capital cost of solar and some domestic battery systems. Currently, one-in-six households in the country has solar panels installed.

After the power for utilities to switch off rooftop solar generation was authorized in June 2020, amid concerns of future blackouts, regulators in South Australia, where 35% of households have installed rooftop solar, have been forced to curtail as much as 67 MW of assorted solar assets. This was enacted to keep net grid demand above 400 MW, and away from the net negative, which would risk blackouts in the region.

The widespread adoption of rooftop solar in Australia has also seen a significant reduction in costs. With a more competitive environment for those installing panels, soft costs–associated with sales, permitting, inspection, margins, and interconnection–have been cut such that the cost in Australia is $0.96 per Watt for a 3-kW system–68% lower than the equivalent price in the USA. With the high capacity factor from Australian installations (18%), the LCOE of rooftop solar is now as low as $43 per MWh in the country, providing an 83% advantage against the average retail price.

In recent years we have seen stark measures proposed and some enacted, by both the Australian Energy Market Operator (AEMO) and the Australian Energy Market Commission (AEMC), to limit rooftop solar power's role on the grid. A draft proposal last month suggested that a "two-way" pricing system should be applied to rooftop solar, under which a modest tax of $0.015 per kWh would be imposed to discourage midday power exports to the grid, threatening to reduce the income from rooftop solar by up to 10%. Such a measure would however encourage the adoption of residential battery storage, while revenue from the tax could be used for necessary transmission upgrades that are plaguing the country's energy system.

Because of this, over 1,464 MWh of residential battery storage has already been installed across the country, almost solely using lithium-ion technologies, with systems in just over 1% of the country's homes.

Brazil

IN BRAZIL, the drivers for the adoption of residential solar-plus-storage are different. Having developed an electricity system that its 80% dependent on large scale hydropower plans, the country is now paying the price for the destruction of its Amazon rainforest. With disrupted water cycles, and facing the country's worst drought in 91 years, the average home in Brazil experiences more than six blackouts every year, driving a customer-desire for home energy security.

As the market with the lowest GDP-per-capita in this study, Brazil also has the lowest electricity demand per household at around 9,108 Wh per day. With limited penetration of both electric heating and air conditioning, and a transport decarbonization strategy built around biofuels, this figure is only expected to rise by around 13% between now and 2050.

Brazil also benefits from a strong solar potential: the average solar system in the country would generate twice as much as the same one in Germany. With the capacity factor from rooftop modules sitting typically at around 18%, a fairly small-scale solar system–of around 15 kW–paired with a 20 kWh battery would be required to achieve full self-sufficiency from the grid. Around 10% of the country's homes have sufficient roof space for such a system, while the rest stand to benefit hugely from systems that provide a slightly reduce level of domestic energy security.

The cost of such an installation is expected to fall from $27,500 in 2022 to $11,000 by 2030, before falling to around $8,000 in the subsequent decade, largely as the soft-costs for solar installations fall.

Compared to the likes of Australia, though, the cost of retail electricity in Brazil is fairly low, sitting between $135 and $160 per MWh in the forecast period, giving residential power

Brazil also benefits from a strong solar potential: the average solar system in the country would generate twice as much as the same one in Germany.

less of an advantage. With an LCOE of $72 per MWh for a solar-plus-storage system using EnerVenue's technology in 2022, such a system is expected to have a current payback period of 18 years. But by 2028, this figure will have fallen to a level acceptable for the top-end of consumers, and by 2040 payback periods will be just six-years on average.

The biggest limitation for Brazil will be the capital available to most of its citizens. The proposed solar-plus-storage system will only account for 63% of total disposable income by the middle of the forecast period; substantially above the 45% figure that is believed acceptable based on historic levels of savings.

The biggest limitation for Brazil will be the capital available to most of its citizens.

One boost to the market is that the Brazilian government, in January of this year, published its Law 14.300, which will allow all renewable energy power generators under 5 MW of capacity to compete in a net metering scheme through to at least 2045. Having previously faced charges for grid connection, the sudden uptake in rooftop solar that we can expect in Brazil will come with an inevitable boost to the country's energy storage market, even if the ability to sell electricity back to the grid may slow the adoption of self-sufficient systems at first.

France

OF THE MARKETS IN THIS STUDY, French homes are among those most limited by their ability to match their power demand with rooftop solar panels—regardless of how big the energy storage system attached. Each kW of solar yielding around 1,200 kWh of power per year with output varying substantially between summer and winter. In a country where average household power demand is set to rise from 11,000 kWh to 17,000 kWh—due to increased adoption of EVs (84%), Electric heating (80%), and Air conditioning (34%) by 2050—over 29 kW of rooftop solar capacity, paired with 14 kWh of battery would be required to ensure energy self-sufficiency on 90% of days.

Because of this, self-sufficiency—as it is defined in this report—is only likely to be possible in the largest 1% of French homes by roof space. Due to their required scale, the cost of such systems, while falling by 60% to $20,000 between now and 2040, are not likely to become widely affordable until at least 2033.

Another limitation in France is that its population benefits from a secure supply of power from its extensive nuclear fleet, with the country being a net exporter of electricity. With rare disruption to home supply, and little incentive to decarbonize from a grid that only relies on fossil-fuels for 10% of its power, French homes have less to gain than most by defecting from the grid.

But in these homes, and within homes that are looking to substantially reduce their energy bills, the business case for home solar-plus-storage solutions in France is still compelling. With a retail power price expected to vary between $190 and $240 per kWh, the payback period of home solar plus storage will fall from 14 years to 8 years by 2030, before plateauing at around 6 years in the long-term. This will happen as the LCOE of home power systems falls by 80%, from $148 per MWh in 2022 to $31 per MWh in 2040.

Another limitation in France is that its population benefits from a secure supply of power from its extensive nuclear fleet.

Germany

GERMANY SUFFERS a similar disadvantage to France in its ability to generate consistent levels of power from rooftop solar systems. But even with the lowest level of solar irradiation of all the markets studies in this report, the elevated cost of electricity in Germany is already driving consumers towards residential power generation systems.

Sitting at $356 per MWh for the average home, retail power prices in Germany are among the highest in the world. Having built a grid based on coal and natural gas, the country's utilities face a hill of investment to shift towards clean energy and meet the Germany's ambition of reaching net zero emissions by 2045, as well as reducing a dependency on Russia for 32% of gas imports in the immediate term.

Because of this, German power prices are unlikely to fall below today's level until after 2040. For consumers in the country, generating their own electricity is already substantially cheaper; even with a capacity factor of just 8%, the LCOE of rooftop solar sits at $143 per MWh and is expected to fall to $33 per MWh by 2040.

Like France, achieving full grid independency in Germany is difficult. With solar output varying season-to-season, and being lower than in most markets, over 27 kW of capacity would be required to meet the demands of the average home in 2040 (up from 22 kW in 2022, due to a rapid projected uptake of electric vehicles).

Paired with 12 kWh of battery storage, up from 10 kWh in 2022, such systems in Germany are expected to cost $20,000 in 2040, having fallen in two-thirds in price from today. Most homes will choose less capital-intensive systems, sacrificing some level of grid-independency.

As such, on the current cost trajectory from solar-plus-storage systems, today's average payback period of 12 years will fall to see mass uptake begin from 2026 onwards. By 2030, this period will have fallen to just 7 years before hitting 4 years in 2040.

The elevated cost of electricity in Germany is already driving consumers towards residential power generation systems.

Japan

THE UPTAKE OF distributed renewables in Japan will come as joint push for cheaper electricity from the consumer perspective, as well as a government drive to become an Asian leader in decarbonization. Given the country's high population density, and price of land, issues surrounding the development of utility-scale renewables could be solved by a boom in rooftop solar plus storage.

The average home in Japan is relatively power hungry, especially when compared to European markets. With a 90+% penetration of both electric heating and air conditioning, the average home demands over 5,500 kWh of electricity per year. Efficiency improvements across appliances will largely offset the growth in EV adoption in Japan, which is somewhat limited by its obsession with hydrogen in the space, so this demand is only set to rise to around 5,900 kWh by 2040.

Japan is also blessed with high levels of solar irradiation, and a rooftop solar capacity factor of around 12%, meaning that grid independence can be satisfied with 21 kW of solar paired with 14 kWh of battery storage. Only 3% of homes in Japan have sufficiency roof space to install such a large amount of solar capacity, so, once again, customers across the country are unlikely to seek full grid independence. There's also little need to, given the fact that Japanese homes experience less than one blackout per year.

The desire to install rooftop solar for Japanese homeowners is primarily economical. With an average retail power price of $221 per MWh expected through to 2040, the LCOE of a rooftop solar installation and Enervenue storage system is already set to save customers money, sitting at $132 per MWh. By 2030, this will have fallen to $49 per MWh, before hitting just $27 per MWh by 2040. The payback period for a system that can provide grid independence, with feed-in permitted, will fall from 15 years to just five years in the same timeframe.

And this is before the bundles of support that we can expect to

The average home in Japan is relatively power hungry, especially when compared to European markets.

see from the Japanese government. Given the country's high population density (36th in the world), and complex topography, utility-scale wind and solar farms are limited in number and capacity. While some focus will be placed on offshore renewables, as floating wind power becomes more feasible, Tepco—Japan's largest utility by far—is exploring new options to decentralize its assets.

The country is already the world leader in terms of solar capacity per square kilometer, leaving rooftop solar as its best opportunity for further expansion. Following this, the country's government has recently set out a strategy to include solar panels on 50% of its own buildings. The next logical step will be a mandate for solar on new residential buildings.

Spain

AS ONE OF THE CONTINENT'S sunniest states, Spain provides the largest opportunity for solar developers in Europe. Like Australia, the country benefits from low installation costs and exceptional solar irradiation, meaning that the average home could defect from the grid by pairing just 11 kW of solar with 13 kWh of battery storage—a system that could feasibly be installed on 7% of homes.

Satisfying the rising demand for electricity of households that are set to increase their adoption of air conditioning, electric heating, and electric vehicles by 2040, the cost of self-sufficiency will fall from $25,000 to $8,000 over the next 18 years, becoming affordable for the average homeowner in 2026.

With the country's national grid being largely dependent on natural gas, retail power prices of around $223 per MWh are already dramatically undercut by the LCOE of rooftop solar ($72 per MWh), a figure which is set to fall by 71% through to 2040.

As such, the payback period of a rooftop solar plus storage system is already close to what will be accepted by some customers. Sitting at 8 years based on today's prices, this figure will fall to four years by 2027 before flattening out at around three years from the mid-2030s.

Avoiding high prices for electricity is already driving customers towards rooftop solar, as consumers fear that the country will not be able to transition away from Russian gas without raising energy bills.

Spain's rooftop solar installs have been doubling almost every year since the government decided to scrap its 'Sun-Tax' in 2018, which required homeowners to pay a levy to the national grid once solar panels were up and running. Solar capacity on private properties increased 102% last year, by 1.2 GW, and there are indications this trend is continuing. Spain's Ministry for Environmental Transition

Avoiding high prices for electricity is already driving customers towards rooftop solar.

expects that installed rooftop solar capacity in the country could reach as much as 14 GW by 2030. Cities such as Barcelona and Madrid are also offering their citizens up to 50% off their property taxes for as much as three years if they put panels on their roofs.

Utilities are already starting to capitalize on this. Barcelona-based Holaluz-Clidom has acquired three installation companies over the past year and expects to add panels to 50,000 rooftops across Spain before the end of 2024. Major utilities like Iberdrola and specialized installers, such as Powen and Solari Power, are also vying to gain a bigger share of Spain's growing rooftop solar market and will inevitably be looking for battery storage offerings to complement this.

USA

MARKETS FOR HOME ENERGY storage in the USA, while varying state-to-state, are significantly different to those elsewhere in the world. In the regions assessed in this study, the average American household consumes more than double the average electricity consumed across the other global markets.

US households tend to be larger and often have higher rates of income. This gives these homes a greater capability to host solar capacity, and as a result of being larger and better financed, a larger proportion of these homes are able to achieve energy self-sufficiency using solar-plus-storage systems.

The economics of energy self-sufficiency are less advantageous in the USA. In the international markets assessed, retail power prices–largely due to subsidized fossil fuels–are on average around 30% lower. Because of this, the payback period for residential power generation is longer, especially in US states with poor net metering rules for solar power.

Similarly, the cost of solar systems in the US can be as much as five times more expensive than the record-low costs experienced in Australia. Soft costs, including those associated with sales tax, permitting, inspection, interconnection, and profit margins, are notably higher than other global markets.

The cost of solar systems in the US can be as much as five times more expensive than the record-low costs experienced in Australia.

California

MIRRORING THE STATE'S ahead-of-the-curve boom in solar power, homes in California will be among the first in the U.S. to benefit financially from becoming fully energy self-sufficient. The region's exceptional solar resources, along with high power prices, have further impetus to action from experiencing frequent and extensive power outages due to wild-fire fears among its utilities.

As seen by the rampant wildfires across the state, climate change is altering how energy and grid officials calculate the state's electricity supply. After the 2020 rolling power shutoffs, California authorities now aim for a buffer of power supply that is 22.5% above projected peak demand—again, adding costs to consumers. California has among the highest power prices in the US at around $220 per MWh for its residents.

Even with this buffer, up to 10% of the state will likely face blackouts this summer as well as over the next five years.

With residents hoping to secure their power, the California Public Utilities Commission is already offering rebates for installing home energy storage technologies and has authorized funding of more than $1 billion through 2024 for its Self-Generation Incentive Plan.

California is also starting to move away from net metering. As NEM 3.0 takes over from NEM 2.0, the state-led compensation available for owners of rooftop solar will start to wane. Rates for exported solar energy could fall by as much as 75%, while monthly charges are likely to increase, and monthly credits will become ineligible for rollover. As this happens—and the grid becomes less of a battery-style source for consumers—the ability of residential batteries in harnessing the value of rooftop solar will increase dramatically,

As seen by the rampant wildfires across the state, climate change is altering how energy and grid officials calculate the state's electricity supply.

with significant knock on affects in adoption rates.

It won't be long before the economic incentive–regardless of government subsidies–is enough to convince customers to move to self-generation. More than one quarter of all homes have sufficient roof space to survive without a grid connection today, but would have to part with as much as $59,000 to do so. However, as solar costs–particularly soft costs–fall dramatically in the US, self-sufficiency, achieved by an average of 23 kW of solar and 30 kWh of battery, will fall to a one-off payment of just $19,200 by 2040.

This figure also accounts for the rapid electrification that will occur in the state over this period. Air conditioning already exists in three-quarters of all homes; this will rise to 85% by 2040, while the use of electric heating systems will rise from 43% to 63%. Most of the 67% rise in household electricity demand, however, will come from a rise in the adoption of EVs, with each household expected to have an average of 1.6 electric vehicles by 2040, each driving over 12,000 miles per year.

Even at today's prices, the LCOE of rooftop-solar-plus storage installations sits at $119 per MWh in California–a 50% reduction against retail power prices.

As stated previously, the installation costs for solar in the US are hugely inflated due to soft costs. But as California installs more capacity, and competition grows between installers, these costs will fall. Along with continued advances in the economies of scale of module producers, the capital costs of rooftop solar will fall by 76% over the next two decades. As consistent across all markets, the cost of battery storage will also fall by more than 90%.

Even at today's prices, the LCOE of rooftop-solar-plus storage installations sits at $119 per MWh in California–a 50% reduction against retail power prices. While today's payback period for these systems sits at around 10 years, this is set to drop massively. By 2030, California's payback period will drop to just four years, before plateauing at around two years once all technologies reach full maturity. However, energy security–otherwise known as backup power–is driving adoption today.

Alongside this, California also benefits from a high level of disposable income among its population. The proposed solar-plus-storage system will only account for 24% of total annual disposable income by the middle of the forecast period.

Florida

KNOWN AS the sunshine state—and a region with extremely high per capita electricity demand—one would expect Florida be a leading market for rooftop solar. However, with some of the cheapest retail prices for its customers, residential power systems have longer payback periods. But as technology costs fall, even this market will see a tipping point where customers will defect from the grid in droves.

Compared to California, for example, retail power is purchased at around 25% of the cost in Florida. These rates have been made available through heavily subsidized natural gas projects, which supplies around three quarters of the state's power. Utility-scale solar projects in the state now sell power at between $15 per MWh and $25 per MWh—below the $45 per MWh to $65 per MWh range for natural gas—but still only account for 4% of its power.

The monopoly that FPL, Duke, and Teco have in the state has left them resistant to free market competition. They are also allowed by the Public Service Commission to pass fuel cost increases directly to their customers; so there is less incentive for them to diversify with solar or other cheaper sources of energy, especially if they can squeeze every last drop of power from their legacy gas facilities.

But the people of Florida use a lot of power. Over 95% of homes have air conditioning installed, while 64% have some sort of electric heating system. Heavy consumption across other devices—including pool heating and pumps in many homes—puts the state at the top of the list in terms of average annual electricity consumption, rising from 18,000 kWh to 21,000 kWh through the forecast period. Small changes in power rates can have a huge impact on their annual bills, which remain subject to huge fluctua-

But the people of Florida use a lot of power. Over 95% of homes have air conditioning installed, while 64% have some sort of electric heating system.

tions in strike prices based on a tiered billing structure.

With such a large power demand, even with Florida's exceptional solar irradiation, achieving self-sufficiency from the grid is difficult. To satisfy the average home's electricity needs, around 26.5 kW of solar capacity is required, rising to nearly 30 kW as further electrification occurs.

The push towards solar-plus-storage will come as part of a drive to reduce grid requirement.

For context, such capacity would demand over 2,000 square foot of roof space, an amount that only exists on around 5% of Florida homes.

The push towards solar-plus-storage will come as part of a drive to reduce grid requirement, rather than eliminate it entirely. With a large number of hurricanes and tropical storms hitting the state each year, Florida has a relatively high number of power outages each year, often sitting between 50 and 100. With these outages lasting several days in many cases, some level of energy independence remains a factor for many.

In many cases, this driver may take precedence over the purely economic benefits of residential solar-plus-storage. Competing with retail power prices of around $70 per MWh–and with limited opportunity to produce excess power from rooftop solar–the payback period of these systems will be around 10 years in 2030. Only later will costs start to fall to more accepted levels, with a payback period of 7 years expected from 2040 onwards.

The capital cost of these systems will also have to be large to match the high energy requirements of Florida homes. Combining 27 kW to 30 kW of solar with 42 kWh to 48 kWh of battery storage–as would be required for self-sufficiency–would cost over $100,000 today, falling to $34,000 in 2030 and $25,000 in 2040. Only from 2030 onwards will the entire system account for less than half of the average homes annual disposable income.

Colorado

COLORADO SITS BETWEEN Florida and California, both geographically, and in the strength of its economic case for residential power systems. Along with its strong solar resource, and medium power prices, the late 2020s will mark the start of the state's shift away from centralized power generation.

Like many states, customers in Colorado are starting to foot the bill for an expensive reliance on natural gas, which provides 24% of the state's power. Having scrambled to buy more gas during a winter storm last year, customers have seen bills rise by 11% as utilities like Xcel look to recover their losses. Power prices in the state currently average around $111 per MWh. In total, coal and gas make up just over half of the state's power production, with renewables–led by wind–accounting for around 42%.

While users have experienced a relatively low rate of power outages historically, the state is looking increasingly exposed to the events that took down Texas' grid last year. The Colorado grid is similarly managed by just a handful of utility companies and lacks connections to its neighbors.

Through its Senate Bill 261, Colorado has been one of the first states to expand its support for solar and battery storage of all sizes, identifying the increased role they will play as more people install electric vehicle chargers and shift to electric building heating. Currently, the penetration of air conditioning, electric heating, and EVs, are 90%, 25%, and 2% respectively. By 2040, it is estimated that electric heating will have risen to 45%, while the number of EVs per household will sit at 1.2.

With the rise, the average annual power demand from a home in Colorado is set to rise from 9,400 kWh, which is fairly low by US standards, to 13,300 kWh. Based on the seasonal fluctuation of solar irradiation in

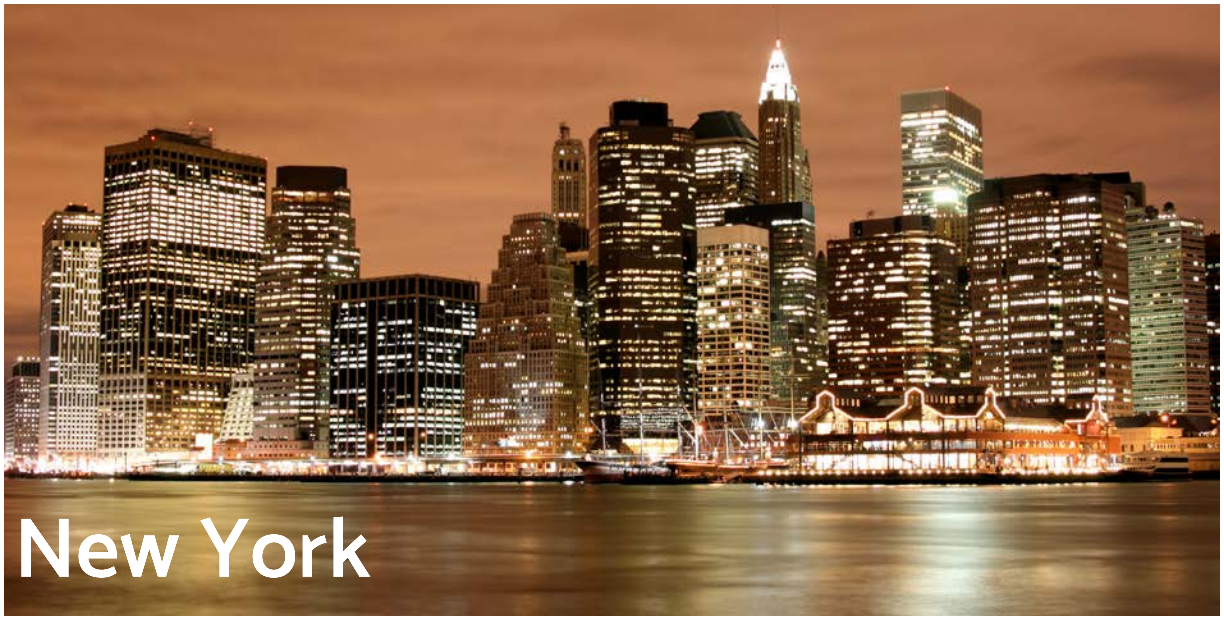
Colorado has been one of the first states to expand its support for solar and battery storage of all sizes,

most of the state, the amount of solar required to satisfy this requires a 30% 'overbuild,' with 17.7 kW required in 2022, rising to 23.1 kW in 2040. Based on the load-profiles of users in the state, this should be paired with a battery capacity of around 29.1 kWh to future proof the system for the rise of household electrification.

This capacity would require just under 1,500 square feet of roof space, but this is available on just 5% of homes; again, reduced reliance on the grid will take precedence over self-sufficiency in most homes.

The levelized cost of energy of the home energy systems outlined in Colorado is currently 26% higher than the cost of retail power. But by 2030, as storage technologies plummet in cost, the LCOE which customers can achieve at home will be half of the electricity rates offered by utilities. At this point, the payback period of such systems–costing $22,100–will sit at around 8 years. By 2050, the cost of the required system will fall to $18,400, with a payback period of 6 years.

In the context of the average household income in Colorado, affordability will be achieved in the first wave, along the same timeline as states like California and Arizona, as well as countries like Spain.



New York

WHEN THINKING OF STATES for solar deployment, New York may not be the first that springs to mind. But driven by high and volatile state energy prices, it offers great opportunity for distributed energy resources which will have a huge impact here.

Due to seasonal fluctuations in the north of the USA, the capacity factor for solar in New York can be as much as 40% lower than in places like Arizona. As such, the state's renewable energy plans are shifting quickly towards capitalizing on its offshore wind potential in its Atlantic waters.

Similarly, with less exposure to extreme weather events, the frequency and severity of blackouts in the state is much lower than it is elsewhere in the country. Household power demand in the state–around 6,800 kWh per year and rising to 10,400 kWh as EV and electric heating penetration rises–is also more than 30% lower than the national average, largely due to smaller and more efficient homes, reduced driving distances for EVs, and greater public charging options.

But due to the low-capacity factor, satisfying a New York home energy needs in 2040 will require around 33.6 kW of solar capacity paired with 22.8 kWh of battery storage. With New York homes often being smaller–and those in the city being largely multi-dwelling buildings–only 1% will have sufficient roof space to install the required amount of solar.

However, retail power prices in New York are expected to vary between $120 and $130 per MWh between now and 2040. The LCOE of home energy systems is already below this, largely due to the overbuild required to account for seasonal solar variation in New York and the additional generation that can be sold back to the grid in summer.

As such, the payback period of residential power systems in New York will fall to around 11 years by 2030, before plateauing at around 8 years in 2040. With the state's high level of household income, such systems will both be affordable and able to provide customers with strong returns on their initial investment.

The capacity factor for solar in New York can be as much as 40% lower than in places like Arizona.

Arizona

IN ARIZONA, all factors seemingly come together to make a market that is primed for rooftop solar and storage. From next year, nearly half of all homes in the state will be able to eliminate their dependency on grid-provided electricity. Others with less available roof space will be able to benefit from installations that will have a payback period of just seven years, falling to less than two years in the long term.

The primary driver behind this is the exceptional solar resources in Arizona. On a utility-level, solar projects have some of the highest capacity factors on Earth at more than 29%. On rooftops this figure is reduced to 18%, which will rise as technologies continue to be improved. Sitting at such a low latitude, seasonal fluctuations have minimal impact on solar output. In fact, many in the state have reported improved performance in the cooler temperatures of winter months.

With summer temperatures often surpassing 40 degrees Celsius, it is unsurprising that Arizona's need for air conditioning pushes its electricity demand to levels that are almost ten-times the global average. Annual electricity demand is now around 12,000 kWh and will rise to over 16,000 kWh as electric heating is installed in 50% of homes by 2040 (up from 30% today). Electric vehicles, which are currently owned by less than one in twenty homes, will rise to a penetration of 1.3 EVs per household by 2040, with at home charging proving more popular than in most US markets.

While such a high electricity demand would normally require a massive solar installation, Arizona's solar potential means that self-sufficiency can be achieved with just 14.0 kW of solar power, rising to 17.4 kW

From next year, nearly half of all homes in the state will be able to eliminate their dependency on grid-provided electricity.

in 2040. With a relatively low population density and large household footprints, between 29% and 43% of homes will be able to satisfy their energy needs with rooftop solar, pairing this with up to 35.5 kWh of battery storage.

The desire to achieve this self-sufficiency will be driven by both economic and security factors. Extreme temperatures, leading to droughts and wildfires, as well as diminishing investment in new fossil fuel infrastructure, are among many reasons that power companies in Arizona are warning of rolling blackouts this summer. They have also cited the slow growth of the state's solar sector, with an increased impetus now placed on the development of distributed generation.

From an economic standpoint, such a generation is a no-brainer. Even at today's elevated costs for solar installations and battery technologies, a system cost of $57,000 could be offset in just 8 years by the savings made from residential power systems.

With Arizona's retail power price sitting well above the $200 per MWh mark, home energy systems already have an LCOE advantage. By 2030, cost reductions will see the payback period fall to just three years. By 2040, this will fall below two years, with the cost of self-sufficiency hitting $15,000–around 17% of the average home's disposable income. With negligible need for maintenance, homes may never need to spend another cent on electricity after this initial investment.

Texas

TEXAS IS AN UNINTUITIVE market for rooftop solar. While experiencing some of the highest solar irradiation in the entire of the U.S, a largely unregulated power market will limit the cost advantage of distributed energy resources. However, the same lack of regulation—responsible for outages in both summer and winter—will see an unparallel desire among households for off-grid capabilities.

February 2021 saw winter storms sweep across the state, causing its worst energy infrastructure failure in its history; more than 4.5 million homes were left without power for several days.

With a 'deep freeze' setting in, power demand—driven by household heating—hit a winter record of 69.15 GW. With many fearing that this could rise as high as 75 GW, the Electric Reliability Council of Texas (ERCOT)—the state's independent system operator (ISO)—issued pleas to some 26 million customers to implement power saving measures including: unplugging appliances, turning down heating, and even wearing jumpers. Across the state, infrastructure and appliances like traffic lights were left without power.

It's not just a winter problem. As in much of the Southern USA, strong summer heatwaves and a high demand for air conditioning—which will only grow as the climate continues to warm—means that Texas is bracing for potentially dangerous and costly blackouts this summer due to extreme weather and volatile gas prices. In July 2022, ERCOT sent out two notices asking Texans to raise their thermostats and avoid using large appliances so usage would not outstrip supply.

Texas is particularly exposed due to its lack of regulation. In 2002, Texas lawmakers opted to deregulate its power market and hand it over to privately

February 2021 saw winter storms sweep across the state, causing its worst energy infrastructure failure in its history.

run operators–only Regional Transmission Operators (RTO's) remained regulated. The premise was to create a competitive marketplace for all types of energy and drive down prices, but essentially it has just compounded ERCOT's monopoly on the state's power market.

Unlike most operators, ERCOT does not have a capacity market, where consistent payments are made to ensure that a sufficient baseload capacity can be provided to the grid at any one time, at a level determined three years in advance. This market is often key to handling extreme weather events, with generators receiving income regardless of whether the power is used or not. Instead, Texas generators can only be paid for per unit of electricity delivered, meaning that costs are cut wherever possible. As a result, energy infrastructure remains largely un-weatherized and unconnected to other markets, meaning regulators can use skyrocketing scarcity pricing to ensure reliability. Last year, power prices surged by up to 4,000%.

In such a freewheeling energy system, average power prices are low, diminishing the advantage of rooftop solar.

In such a freewheeling energy system, average power prices are low, diminishing the advantage of rooftop solar. In Texas, average retail power prices of just $62 per MWh are just one quarter of those seen by many customers in California. In fact, billpayers in Texas often face an unusual rate structure whereby the more energy they use, the less they pay for each unit.

So even with a capacity factor of 16% - rivalling that of Arizona, Spain and California–the LCOE of rooftop solar alone will not undercut retail power until 2024, while solar-plus-battery installations will have to wait until 2026. Even then, payback periods will be as high as 9 years in 2030–in most markets that would be unacceptable to consumers until they fell to the 6-year mark expected in Texas by 2040.

However, the consequences of Texas' power outages will be enough to convince many homes to pay a slight premium for their energy needs; as many as 700 deaths have been blamed on the blackouts in 2021.

Like many homes in the south of the country, household electricity demand in Texas sits among the highest in the world and will rise to around 19,000 kWh as EV adoption rises towards 1-EV-per-home in 2040, with Texans driving an average of 15,000 kilometers per year. This will also be driven by a 95% penetration of air conditioning, as well as electric heating being present in 86% of homes–up from 66% today.

Satisfying this huge demand would require 20.7 kW of rooftop solar capacity, paired with a huge 43.2 kWh of battery storage. Limited by the amount of rooftop solar available, only 13% of homes are likely to have the ability to go fully grid independent all year round, but many others will be able to protect themselves sufficiently from the risk of severe outages for a cost of $18,000 by 2040.